Sea Temperatures, Hawaiian Island Area[1]

A Study of the Distribution of Ocean Temperatures in the Surface and Subsurface Layers Based upon Bathythermograph Observations

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INTRODUCTION

Since 1940 the supply of available sea-temperature information has been greatly increased through the use of the bathythermograph (Spilhaus, 1940), an instrument which may be lowered from moving vessels to provide a continuous trace of temperature against depth. The temperature values are usually accurate to within ± 0.3° F. Greatest depths attained are approximately 180, 450, or 900 feet, depending upon the type of bathythermograph used. A detailed sea-temperature study of the Hawaiian Island area (the area from 15° to 30° north latitude and 150° to 165° west longitude) was prepared by the Bathythermograph Section at Scripps Institution of Oceanography (Leipper and Anderson, 1948; Hiatt, 1948). This study, made from 5,407 observations, is the basis of the summary presented here. A similar study was made in the Philippine Island area (Leipper and Wood, 1947) but has not yet been published.

Purpose of the investigation

The purpose of this investigation is threefold: (1) to show the horizontal and vertical distribution of temperature; (2) to show the amount of data that is available and how it is distributed; and (3) to further the development of a model temperature-distribution study that may in the future be used for other regions.

Availability of bathythermograph data

The file of bathythermograms for the Pacific and Indian Oceans is maintained at Scripps Institution of Oceanography, La Jolla, California, and at the U. S. Hydrographic Office, Washington, D. C. Copies of observations may be requested from the Hydrographic Office.

Acknowledgments: Clerical and statistical assistance was furnished by Misses A. Kutz, V. Wilburn, M. Hunter, M. Oakes, E. Trowbridge, and Mrs. B. Rimbach. Drafting was done by Mrs. M. Robinson and photographic work by Mr. P. Williams.

DISTRIBUTION OF BATHYTHERMOGRAMS

The bathythermograph observations used for this investigation cover the period from January, 1941, to November, 1947. Of the bathythermograms available, 5,377 were suitable for use.

The time distribution of the bathythermograms is shown by Tables 1, 2, and 3 following the text. Table 1 shows the yearly percentage distribution; Table 2, the total monthly percentage distribution; and Table 3, the monthly percentage distribution in different years. The space distribution of the bathythermograms is shown in Figure 1. (Figures appear at the end of the text and tabular material begins on page 232.)

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Two groups of cruises, designated as the *H* and *Q* cruises, were made near the entrance to Pearl Harbor during 1944 and the early part of 1945. The following tabulation shows the dates of these cruises as well as the number of bathythermograph observations taken.

H AND *Q* CRUISE DATA

CRUISE	DATE	NUMBER OF BATHY-THERMOGRAMS
Q-1	2/24/44– 3/29/44	60
Q-2	3/29/44– 4/22/44	60
Q-3	4/23/44– 5/14/44	60
Q-4	5/15/44– 6/26/44	60
Q-5	6/27/44– 9/ 4/44	60
Q-6	9/15/44–11/13/44	60
Q-7	11/14/44– 2/12/45	60
Q-8	2/12/45– 2/20/45	7
H-1	3/13/44– 3/29/44	42
H-2	3/29/44– 4/17/44	56
H-3	4/17/44– 5/ 6/44	57
H-4	5/ 6/44– 5/30/44	60
H-5	6/ 1/44–10/ 9/44	108
H-6	11/16/44– 2/20/45	63

HORIZONTAL TEMPERATURE DISTRIBUTION

Horizontal temperature distribution based on averages by 1-degree quadrangles of latitude and longitude

The horizontal distribution of average temperature at the surface and at depths of 100 feet, 200 feet, and 300 feet is shown in Figures 2 to 13 for each of the 12 months of the year. March and September average temperatures were, respectively, lowest and highest of the year. June and December were months having temperature distributions typical of months of transition.

In preparing the monthly average temperature charts, the following procedure was used: At each depth level, all available temperatures for each 1–degree quadrangle were averaged by months. To obtain time continuity, the monthly averages for each quadrangle where there were sufficient data were plotted against time, and a curve, smoothed visually, was drawn through the points. Monthly average temperatures were then read from this smoothed curve. The values for each month were plotted on a map by position, and the isotherms were drawn.

The ocean current systems which are present affect the horizontal temperature distribution. In March the southern portion of the Hawaiian Island area is under the influence of the northeast trade winds with a resulting ocean current toward the west known as the North Equatorial Current. In the northerly portion of the area the North Pacific Current flows toward the southeast. Between these two currents as shown in Figure 14 is a region where the flow is variable (Sverdrup, Johnson, and Fleming, 1946: 723, appendix, Chart VII). This region coincides with the region where the pattern of isotherms is most irregular, as shown in Figures 2 to 13.

The extremes of average temperature

For each month of the year, at particular depths, the maximum average monthly temperature occurring in any 1-degree quadrangle of the Hawaiian Island area was selected. Similarly, the minimum average was obtained. These, together with the differences between them, are presented in Table 4 at several depths for each month. At the surface and at 100 feet, the differences are smaller during the summer than during the winter. At 200 and 300 feet, the differences appear to be almost constant.

Table 5 (page 233) shows results of analysis of the smoothed annual temperature-variation curves which were drawn for each 1-degree quadrangle as explained earlier. An examination of the table shows that the minimum occurred the greatest percentage of the time in March at all levels except 300 feet; and the maximum, in September at all levels except 300 feet. At 300 feet the minimum occurred most often in April and the maximum most often in October.

Figures 16 and 17 present the maximum and minimum monthly average temperatures, respectively, for the surface and the 100-, 200-, and 300-foot levels. To obtain Figure 16, the highest monthly average temperature at each depth in each quadrangle was plotted, regardless of the month or year in which it occurred, and isotherms were drawn. Figure 17 was prepared similarly for lowest monthly average temperatures.

The highest single surface temperature recorded in the Hawaiian Island area was 90° F. at 19° N and 157° W in August, 1942, while the lowest single temperature recorded was 60.9° F. at 28° N and 163° W in January, 1947.

Annual sea temperatures at a depth of 400 feet

As is apparent in Figures 22 and 27, sea temperatures at a depth of 400 feet have only a small annual variation. Values for all months of the year have therefore been averaged together by 1-degree quadrangles to obtain the annual average. These annual averages were plotted by position and isotherms drawn (see Figure 15). This figure, when compared with Figures 22 and 27, indicates that at 400 feet the variation of sea temperature with position greatly exceeds the variation with time.

Comparison of average temperatures in different years

Figure 18 compares the annual variation of temperature at the surface, 100 feet, 200 feet, and 300 feet for each of the years 1943 to 1947 with the average annual variation for all years combined. There is considerable difference between the curves representing different years. The year 1943 was warmer than average at the surface and 100 feet. Not enough data were available to show the deviation at 200 feet and at 300 feet in this year. The year 1944 was virtually an average year at the upper two levels, while at the two lower levels there was some variation from the average. The year 1945 was definitely a warmer-than-average year in the upper two levels, while in the lower two it was generally warmer with a few months colder than average. The first part of the year 1946 was definitely warmer than average, while the latter part of the year was colder than average at all levels. The year 1947 was a colder-than-average year at all levels with the deviation being the greatest in the upper 100 feet.

Average temperature in the vicinity of Oahu

Figure 19 shows the temperature distribution in the vicinity of Oahu for the surface, 100 feet, 200 feet, and 300 feet. The isotherms at each depth are based upon averages computed for each 10-minute quadrangle of latitude and longitude. Thus the details of the average temperature distribution near Oahu are shown. In this region many observations are available and detailed information may have practical value.

VERTICAL TEMPERATURE DISTRIBUTION

Southwest-northeast cross section

Figures 20 and 21 present average southwest-northeast temperature-depth sections for winter and summer months, respectively. All available bathythermograms for the two periods of time, and within the band denoted in Figure 1, were used to obtain the averages at various positions and depths. These averages form the basis of the sections.

Monthly average temperature-depth curves

Figure 22 shows curves through the average temperatures at different depths for a 5-degree quadrangle covering the area 20° to 25° N and 155° to 160° W. These curves were obtained by averaging all available temperatures for each month at 10-foot depth intervals down to 100 feet and at 25-foot intervals down to 425 feet, plotting these averages against depth, and joining the points. Such curves do not show the typical temperature-depth structure because of smoothing which occurs in averaging. The number of temperatures included in the average is shown beside each point.

Figure 23 shows the average temperature-depth curves for two specific points. The curves labeled "H" are taken from *H* cruise data. These cruises consisted of 386 bathythermograph observations from March, 1944, to February, 1945. All data were collected at 21° 18′ N and 157° 53′ W, approximately 0.75 mile south southwest of Honolulu in 100 feet of water. These data were averaged together by months with the results as shown in the figure. The curves labeled "Q" are taken from *Q* cruise data. These cruises consisted of 427 bathythermograms from February, 1944, to February, 1945. The station was located at 21° 18′ N and 157° 58′ W about 1.75 miles due south of the entrance to Pearl Harbor in about 600 feet of water.

These two stations are located approximately 5 miles apart, and the data were taken during the same year. It is interesting to note that during the months of March and April the average curves were identical, but during the other months the *H* cruise data showed appreciably lower temperature at all depths.

Typical bathythermograms

Figure 24 contains copies of actual bathythermograms selected as typical of a northern and a southern portion of the area under study for the months of March, June, September, and December. These single records show several prominent features which are not apparent in curves drawn through average temperatures at selected depths. One of these features is the deep layer of nearly isothermal water which is present on several of the individual curves. Another is the strong thermocline. Each of these characteristics is typical of nearly all individual bathythermograms in this area but the process of averaging and the decreasing frequency of temperature readings with depth causes them to disappear from the average temperature-depth curves. Thus it is desirable to consider typical single observations as well as average curves.

Depth of the virtually isothermal layer

The average depth of the virtually isothermal layer for summer and winter periods is shown in Figure 25. The charts were prepared by reading from the bathythermograms the layer depth to the nearest foot and averaging the results by 1-degree quadrangles. These data were then plotted, and isolines of depth were drawn. The virtually isothermal layer is, on the average, deeper than the 180-foot maximum depth for the "shallow" bathythermograph; hence, the "deep" bathythermographs are the only ones that reach the thermocline. As a result, only 40 per cent of the total number of bathythermograms available for this study were used in establishing the layer depth. Two conclusions may be drawn from Figure 25: the layer depth varies considerably with position; and during the winter the depth is greater than during the summer.

An attempt was made to draw layer-depth charts for each month of the year. Although many observations were available, the variability within any given month and any given quadrangle was so great that it was not possible to draw isolines that exhibited good continuity.

Diurnal and annual variation of temperature

In August, 1941, the U.S.S. "Pyro" took bathythermograph observations every hour in the area 21° to 34° N and 138° to 157° W. These data were analyzed by H. U. Sverdrup and others to determine the diurnal variation of temperature. Figure 26 shows the results of this analysis.

The wind-stirred layer at the time of these observations was approximately 120 feet thick with 75° F. as the average temperature of the layer. Between the surface and 120 feet the temperatures were read at 30-foot intervals. The temperature differences between 120 feet and each other level were determined and plotted. The figure shows that the upper layer is nearly isothermal during the early morning, but that the vertical gradient increases as the effect of solar radiation is felt. The time of maximum temperature occurs later at greater depths because time is required for heat to reach these depths by conduction.

The annual variation of temperature at subsurface depths in the area 20° to 25° N and 157° to 160° W is shown in Figure 27. The maximum temperature occurs at 400 feet approximately 1.3 months later than at the surface. A secondary maximum is indicated in January. The maximum shown at 400-foot level in April is probably not a real feature but one due to the uneven frequency distribution of observations.

ADDITIONAL DATA AVAILABLE

In addition to what has been published here, certain further investigations have been made and results are available from the Scripps Institution of Oceanography. Among these results are charts of the distribution of observations by months and hydrographic station data.

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TABLES

TABLE 1
DISTRIBUTION OF BATHYTHERMOGRAMS BY YEARS

YEAR	PERCENTAGE
1941	3.2
1942	2.5
1943	16.0
1944	43.0
1945	15.1
1946	11.7
1947	8.6

TABLE 2
DISTRIBUTION OF BATHYTHERMOGRAMS BY MONTHS

MONTH	PERCENTAGE
January	7.1
February	10.0
March	10.4
April	11.8
May	9.9
June	6.8
July	7.2
August	9.9
September	9.2
October	6.4
November	6.3
December	4.9

TABLE 3

DISTRIBUTION OF BATHYTHERMOGRAMS BY MONTHS IN DIFFERENT YEARS
(All figures are given as percentages.)

MONTH	1941	1942	1943	1944	1945	1946	1947
January	0.0	0.0	0.3	5.8	23.4	2.1	7.0
February	1.2	13.4	18.4	7.3	13.6	7.0	7.8
March	5.3	0.0	13.0	8.7	9.4	1.7	30.0
April	0.0	11.2	13.2	12.0	10.2	9.2	15.9
May	2.4	22.4	9.5	14.1	2.8	2.9	11.3
June	1.8	11.9	1.8	7.8	3.4	5.1	17.6
July	3.5	0.0	5.0	7.2	6.9	9.1	10.4
August	42.9	14.9	3.6	10.3	8.3	16.7	0.0
September	2.9	9.7	12.1	8.0	6.3	20.5	0.0
October	10.6	0.0	7.0	7.0	3.8	11.0	0.0
November	24.7	0.0	5.0	6.6	5.4	8.7	0.0
December	5.3	16.4	11.0	5.3	6.4	5.9	0.0

TABLE 4

MAXIMUM AND MINIMUM MONTHLY AVERAGE TEMPERATURES
AT DIFFERENT DEPTHS

	MAXIMUM				MINIMUM				DIFFERENCE			
Depth in feet	0	100	200	300	0	100	200	300	0	100	200	300
January	80	79	78	78	68	68	66	64	12	11	12	14
February	79	78	78	77	67	66	65	64	12	12	13	13
March	78	77	77	76	66	67	64	64	12	10	13	12
April	78	77	77	76	68	68	64	64	10	9	13	12
May	79	78	78	77	70	69	66	64	9	9	12	13
June	80	80	79	77	74	71	68	64	6	9	11	13
July	82	80	80	78	76	73	66	64	6	7	14	14
August	82	81	81	79	77	75	68	66	5	6	13	13
September	82	82	81	80	77	76	67	67	5	6	14	13
October	82	82	82	80	76	75	68	66	6	7	14	14
November	82	81	81	80	72	72	68	67	10	9	13	13
December	80	80	80	79	70	70	67	66	10	10	13	13

TABLE 5

MONTHS IN WHICH MAXIMUM AND MINIMUM TEMPERATURES OCCURRED MOST OFTEN ON
SMOOTHED ANNUAL VARIATION CURVES WHICH WERE DRAWN
FOR EACH 1-DEGREE QUADRANGLE

MINIMUM			MAXIMUM		
Depth	Month	Frequency	Depth	Month	Frequency
Feet		*Per cent*	*Feet*		*Per cent*
Surface	March	56.4	Surface	September	64.5
100	March	57.9	100	September	71.0
200	March	46.6	200	September	51.1
300	April	39.0	300	October	40.7
All	March	48.9	All	September	54.9

FIGURES

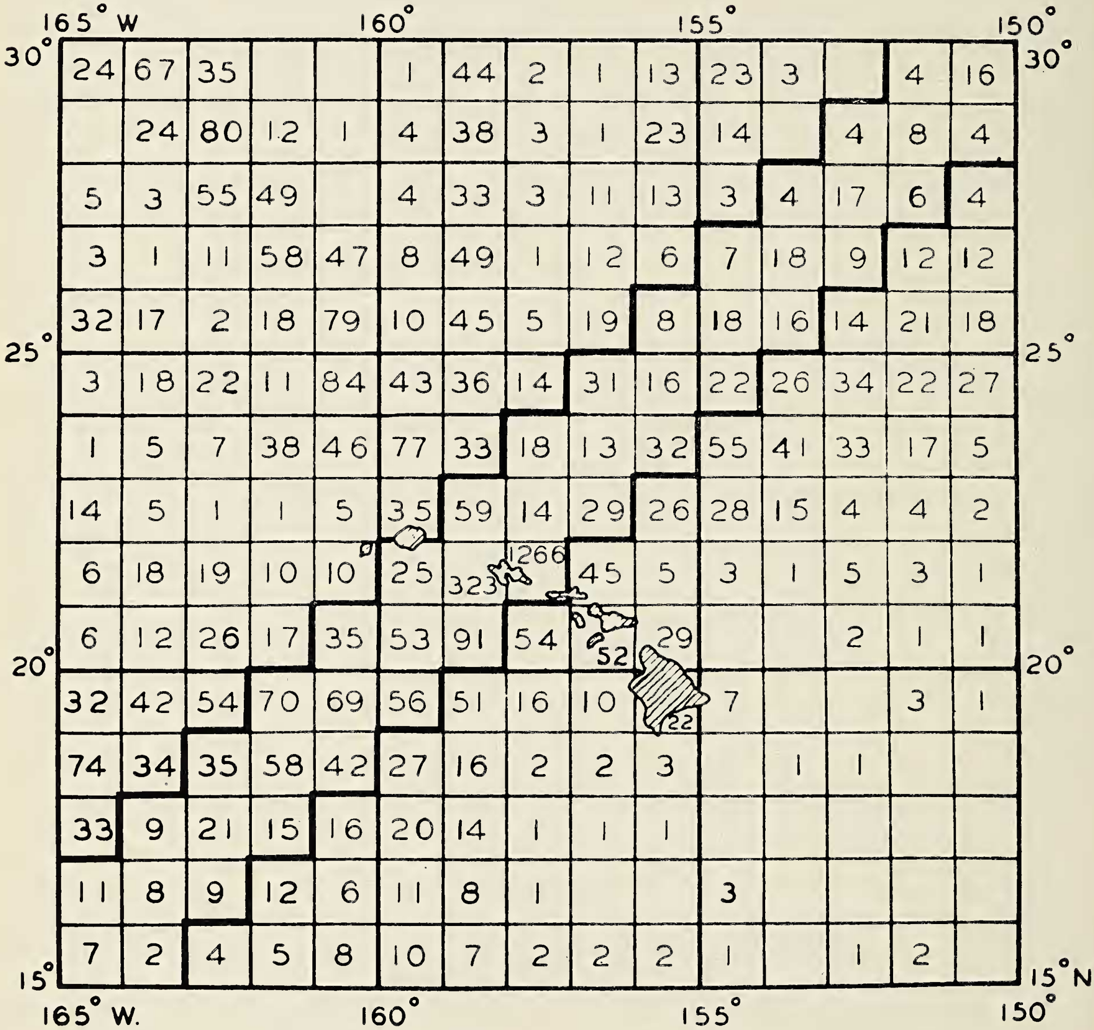


FIG. 1. Distribution of bathythermograph observations processed prior to November, 1947.

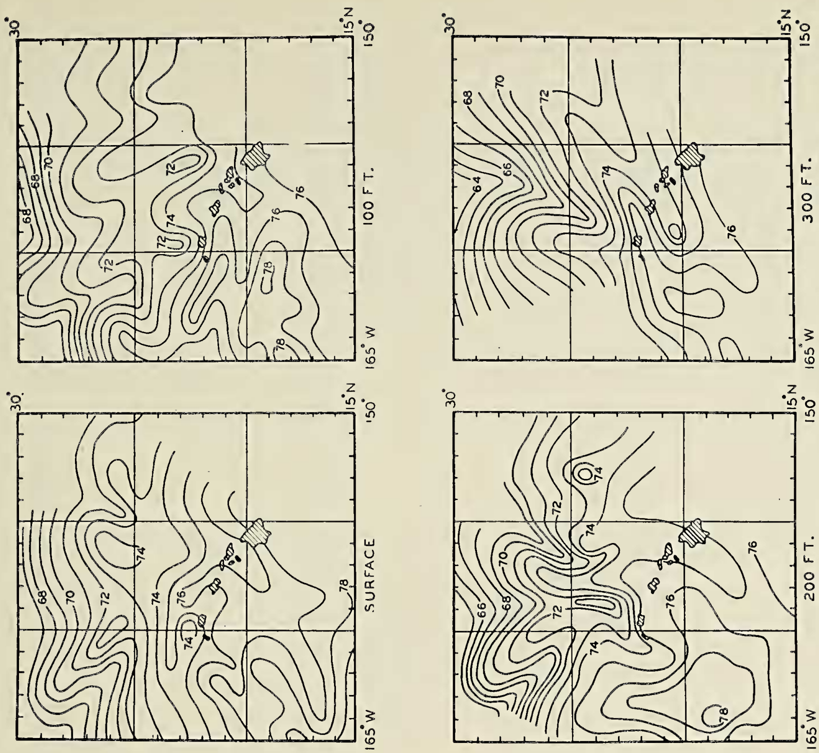


FIG. 3. FEBRUARY, average sea temperatures (° F.) at selected depths (1941–1947).

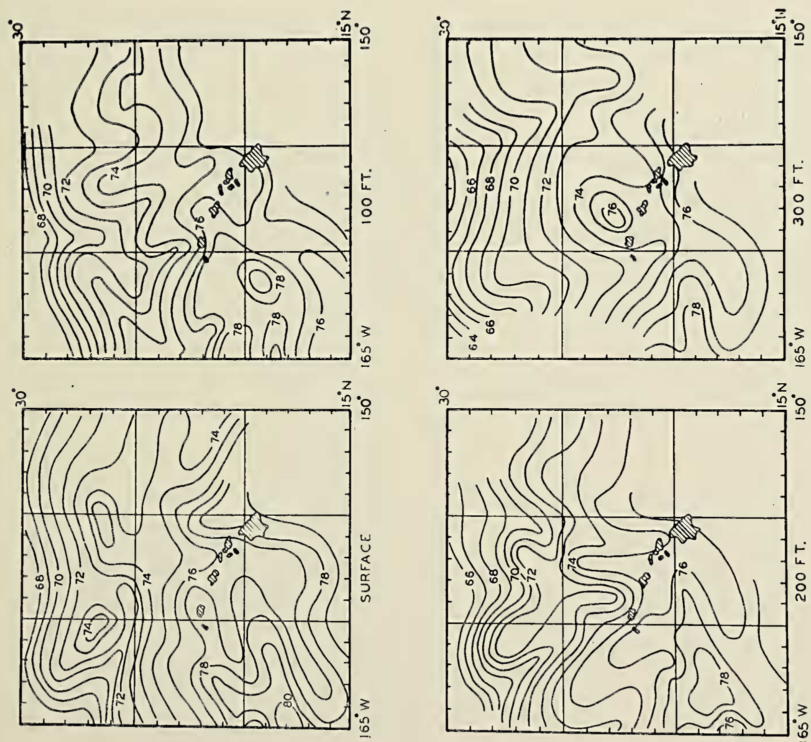


FIG. 2. JANUARY, average sea temperatures (° F.) at selected depths (1941–1947).

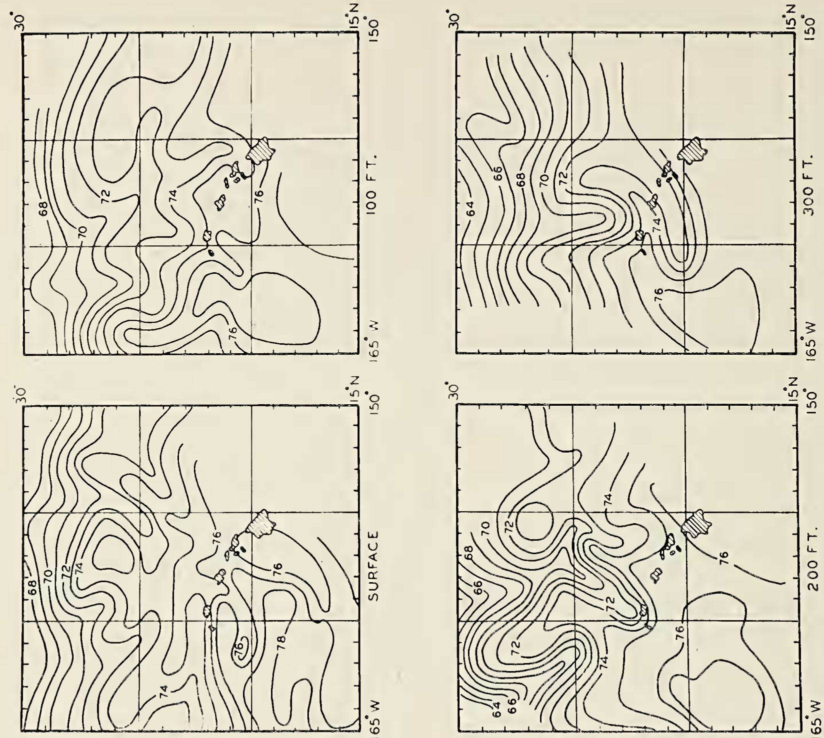


FIG. 5. APRIL, average sea temperatures (° F.) at selected depths (1941–1947).

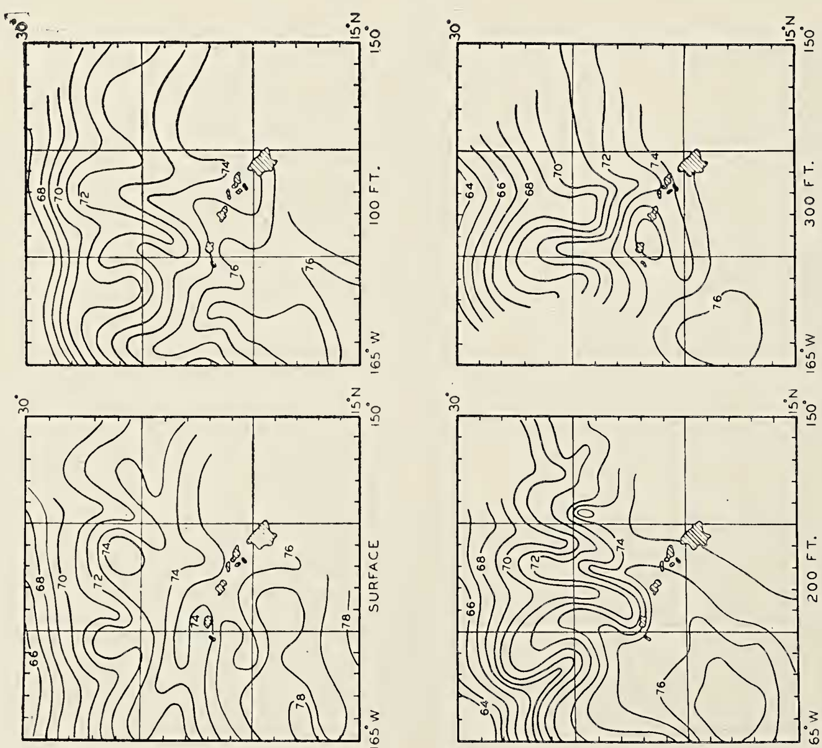


FIG. 4. MARCH, average sea temperatures (° F.) at selected depths (1941–1947).

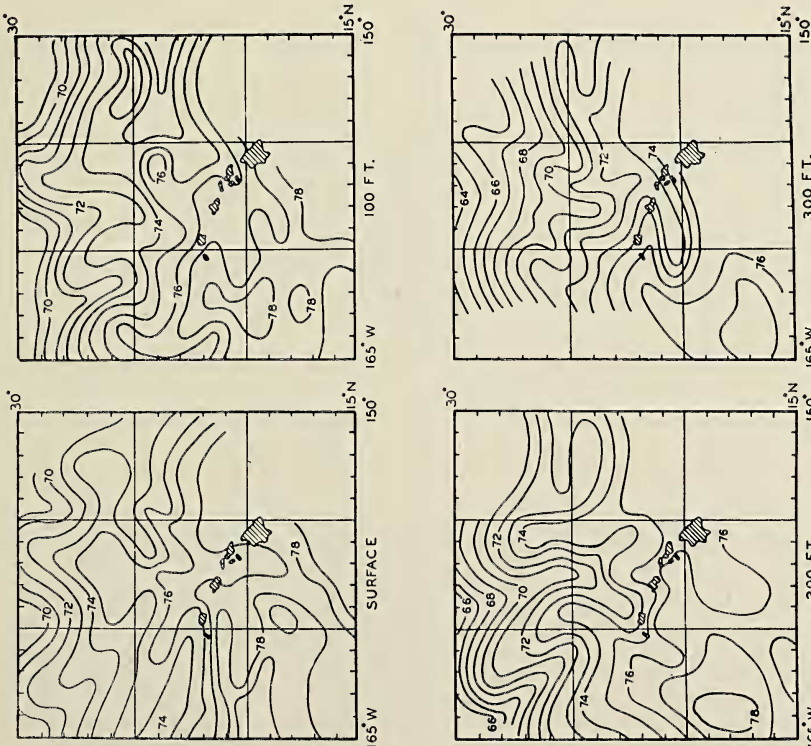


FIG. 6. MAY, average sea temperatures (° F.) at selected depths (1941–1947)

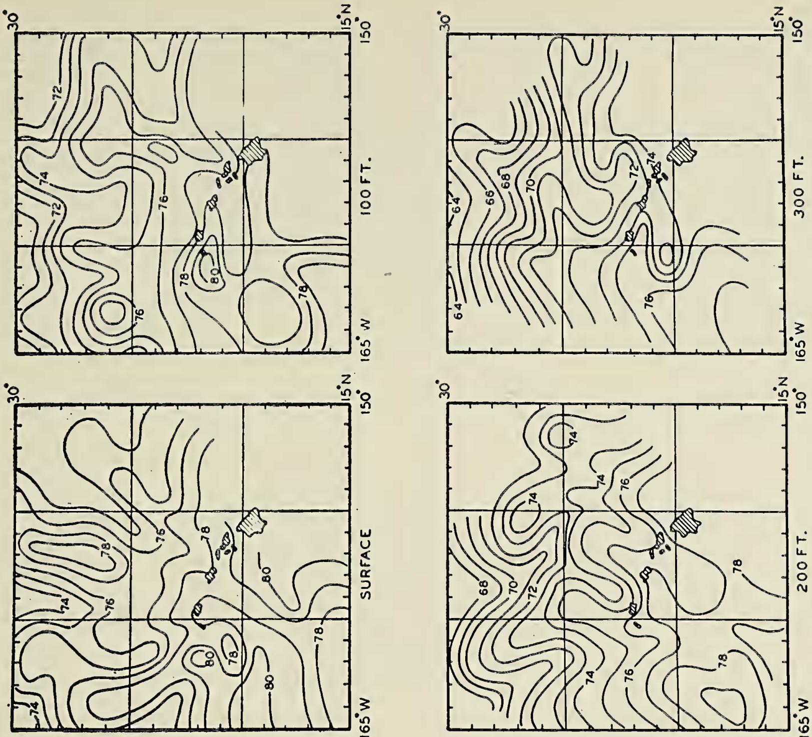


FIG. 7. JUNE, average sea temperatures (° F.) at selected depths (1941–1947).

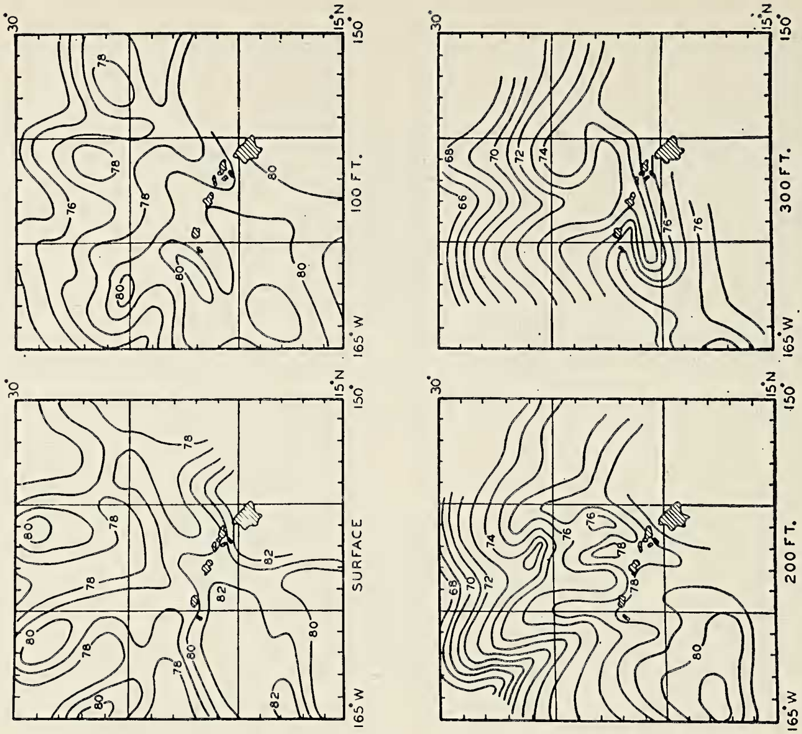


FIG. 9. AUGUST, average sea temperatures (° F.) at selected depths (1941–1947).

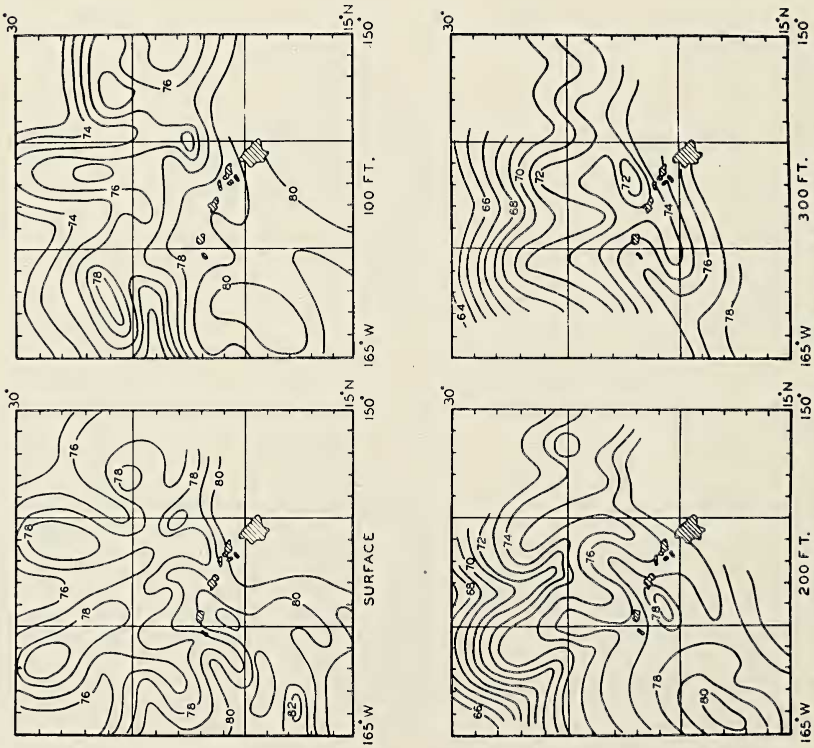


FIG. 8. JULY, average sea temperatures (° F.) at selected depths (1941–1947).

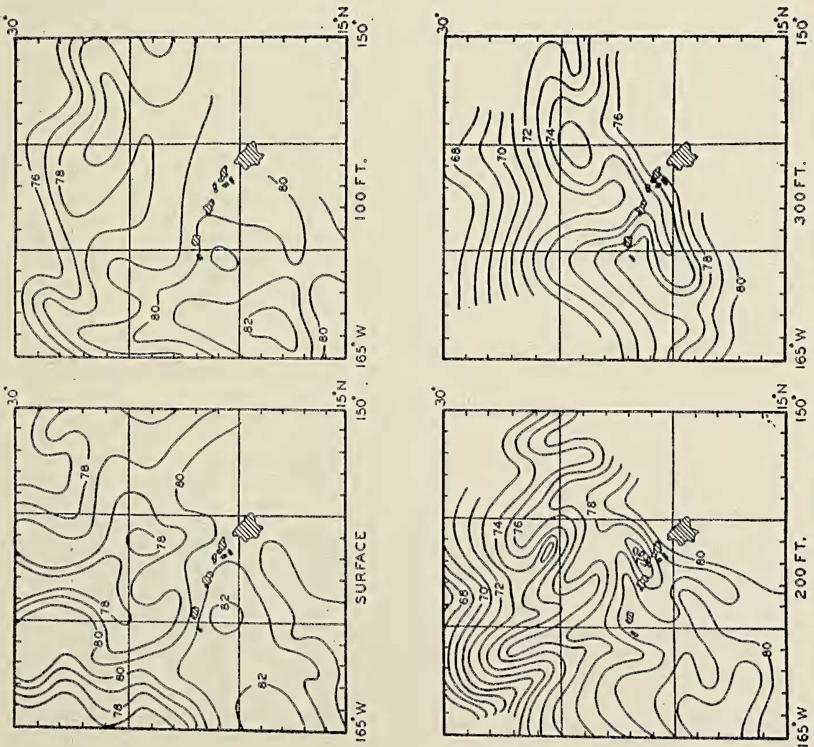


FIG. 10. SEPTEMBER, average sea temperatures (° F.) at selected depths (1941–1947).

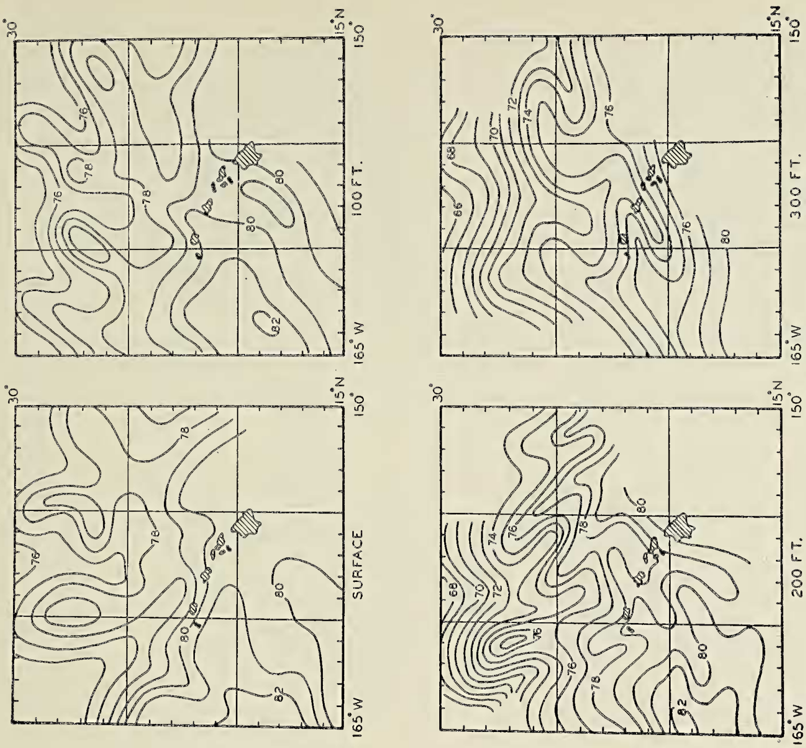


FIG. 11. OCTOBER, average sea temperatures (° F.) at selected depths (1941–1947).

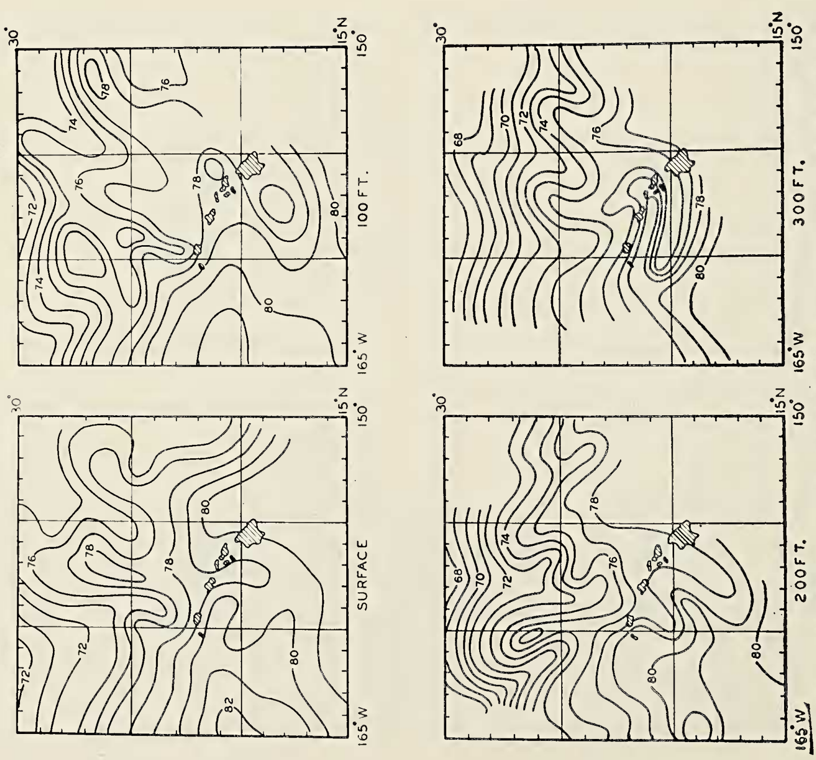


FIG. 12. NOVEMBER, average sea temperatures (° F.) at selected depths (1941–1947).

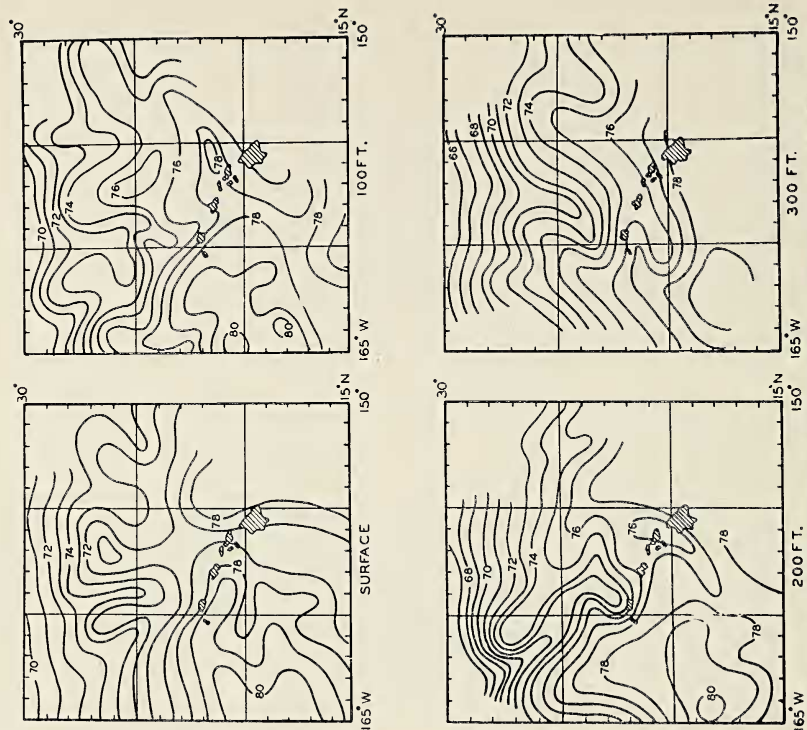


FIG. 13. DECEMBER, average sea temperatures (° F.) at selected depths (1941–1947).

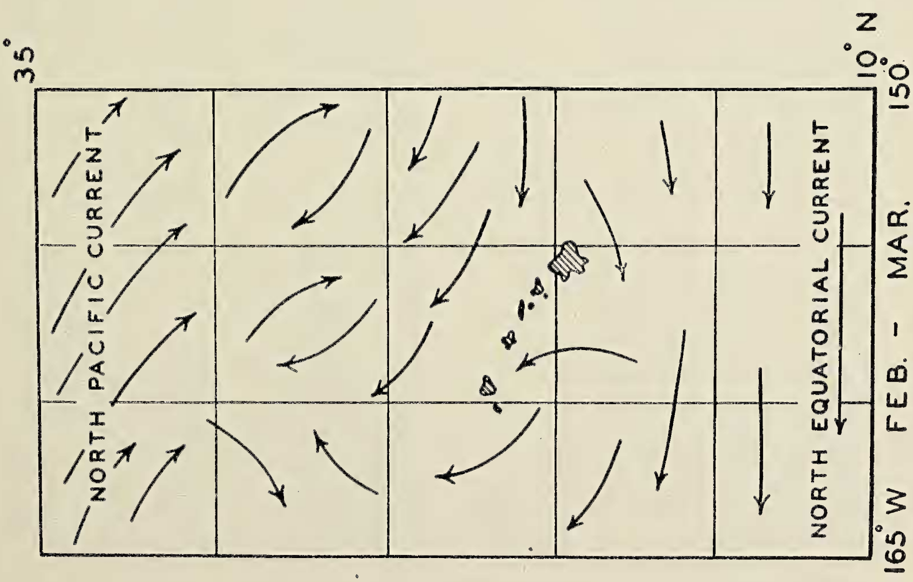


FIG. 14. Sketch of ocean currents; after Sverdrup.

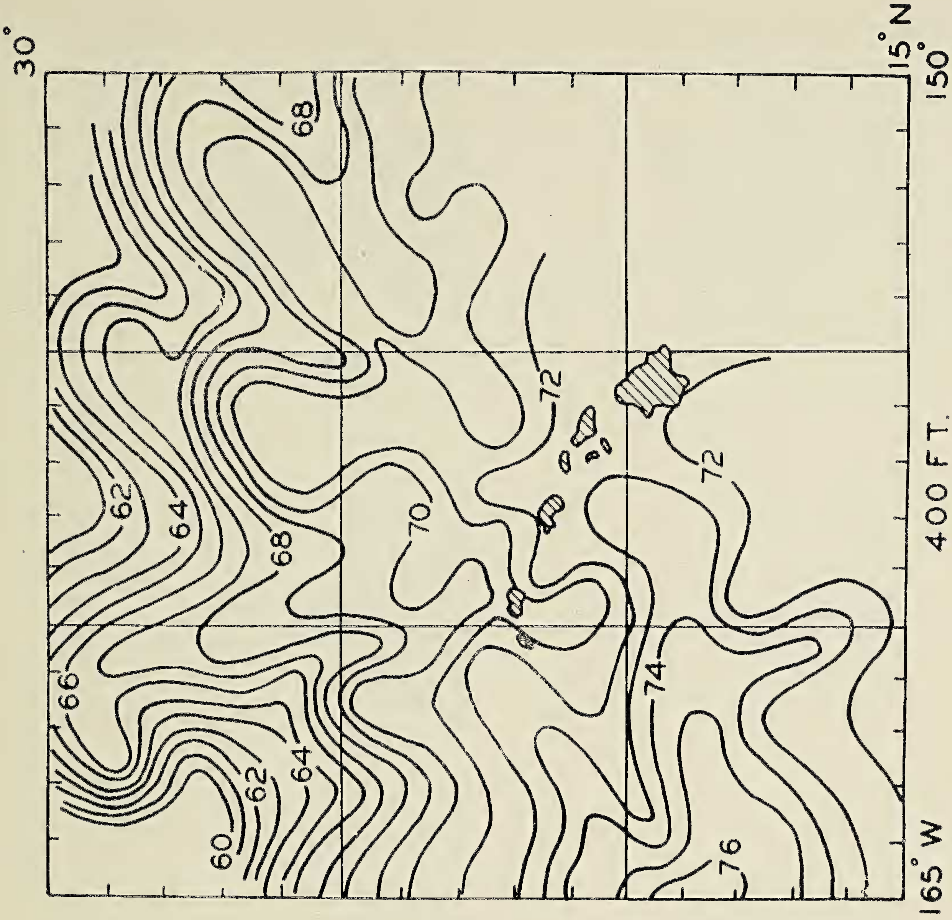


FIG. 15. Annual average sea temperatures (° F.) at 400 feet.

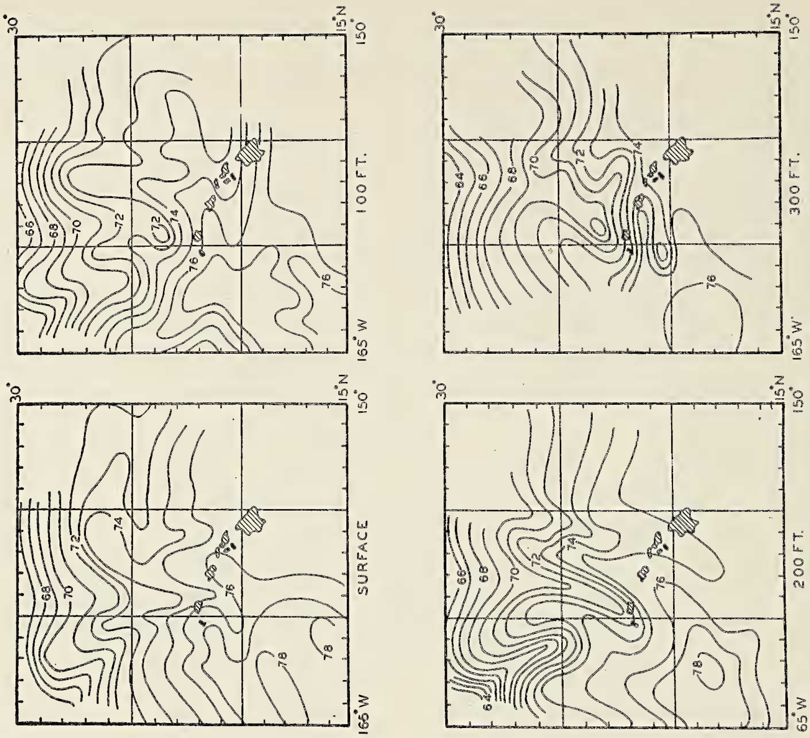


FIG. 17. Minimum monthly average sea temperatures (° F.), (1941–1947).

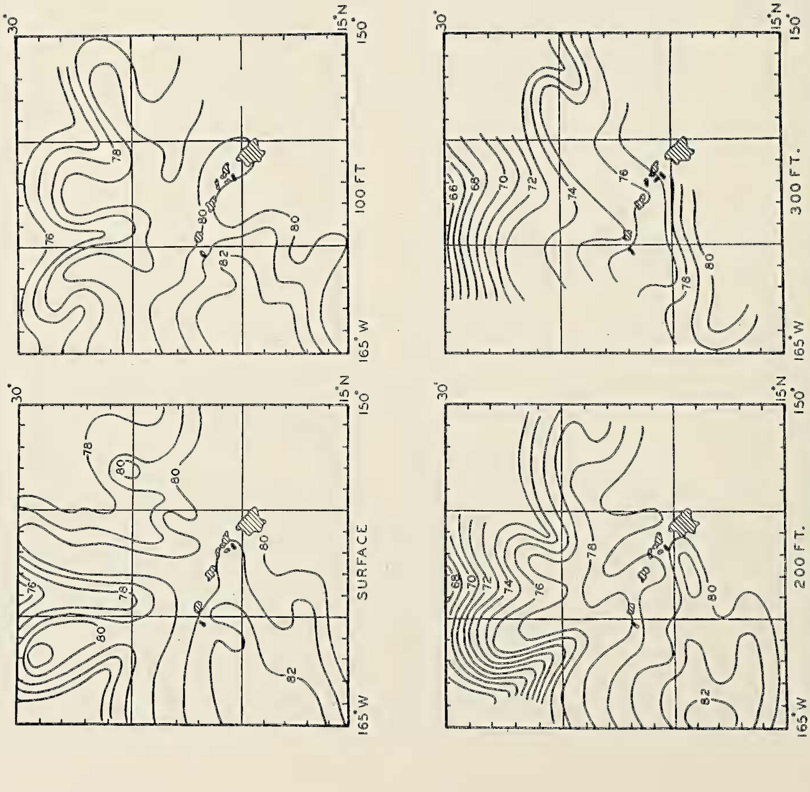


FIG. 16. Maximum monthly average sea temperatures (° F.), (1941–1947).

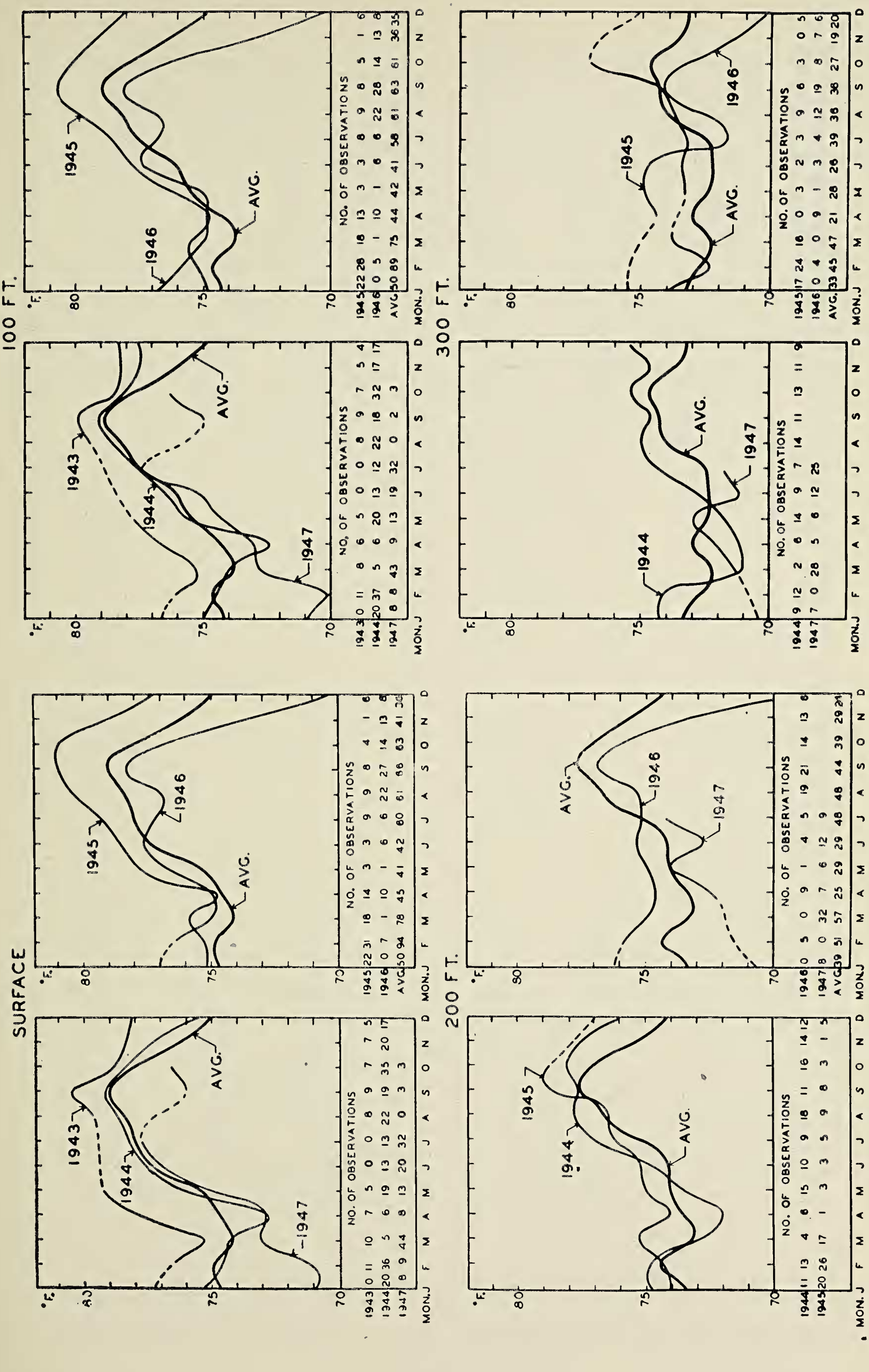


FIG. 18. Annual sea temperature variation (° F.) shown by curves through monthly averages (1943–1947), 20°–25° N, 155°–160° W.

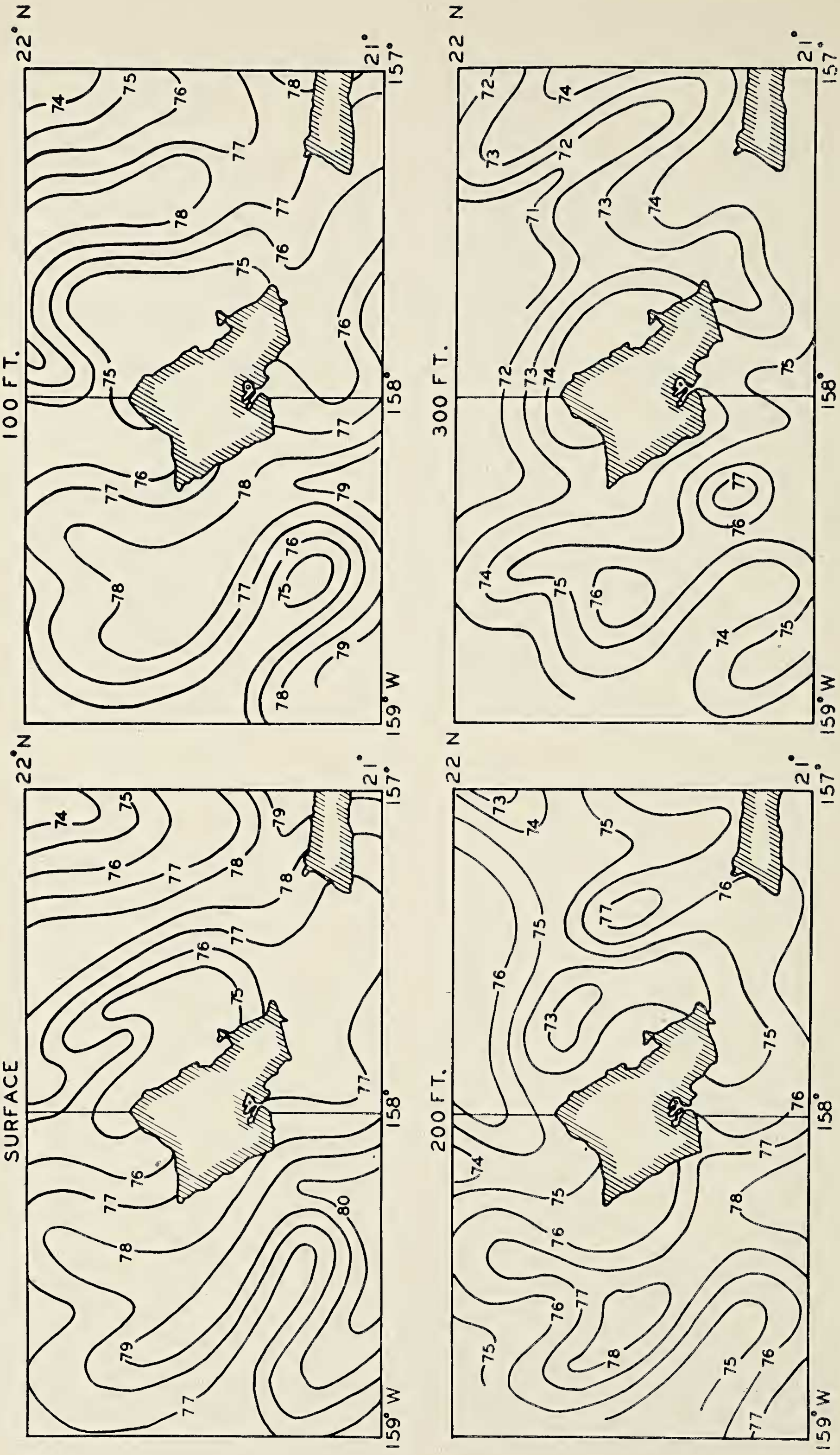


FIG. 19. Annual sea temperatures (° F.) in the vicinity of Oahu (1941–1947).

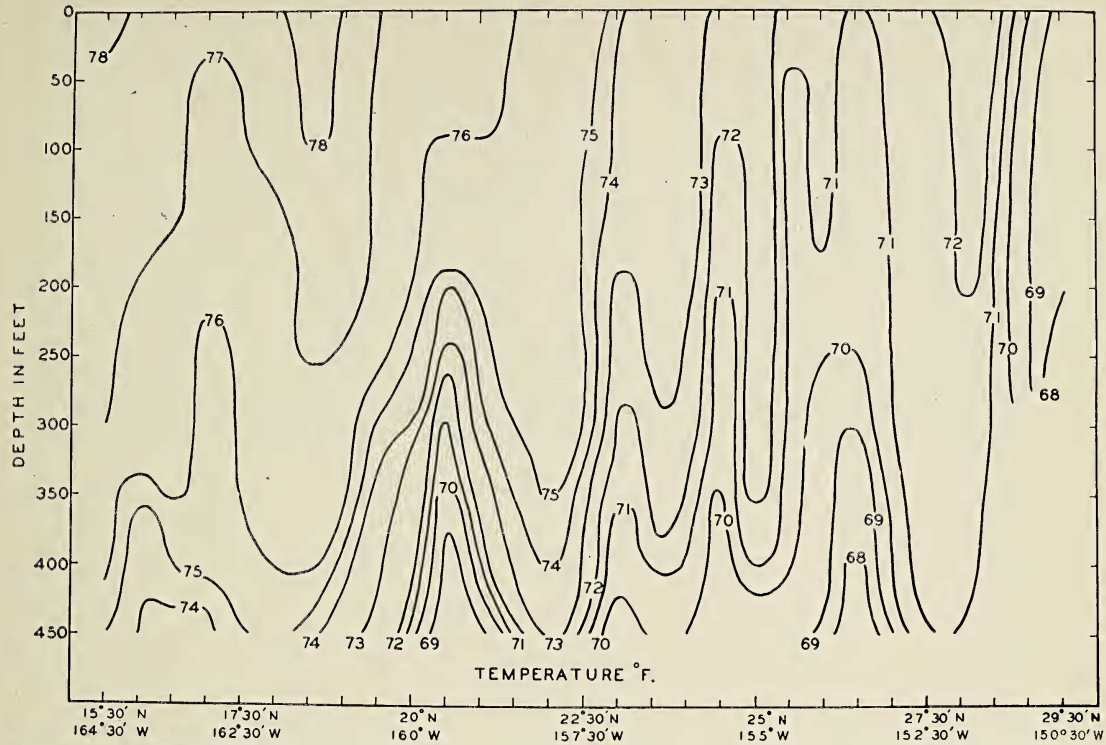


FIG. 20. SW–NE sea temperatures (° F.). Cross section (January, February, March, 1941–1947).

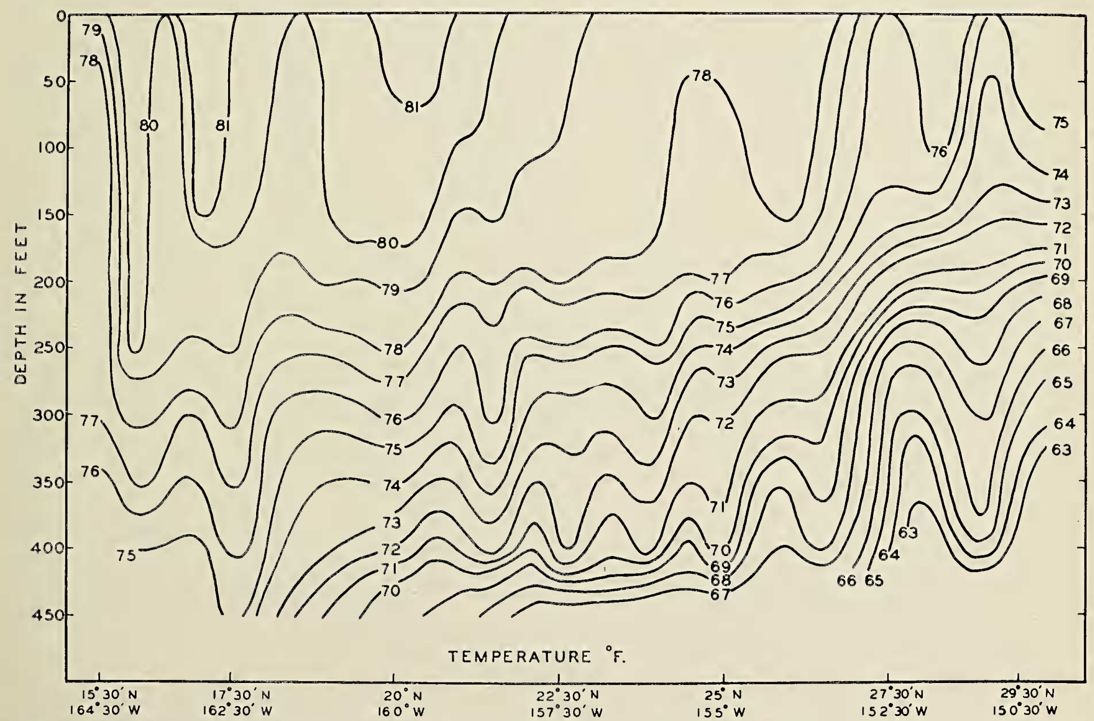


FIG. 21. SW–NE sea temperatures (° F.). Cross section (August, September, October, 1941–1947).

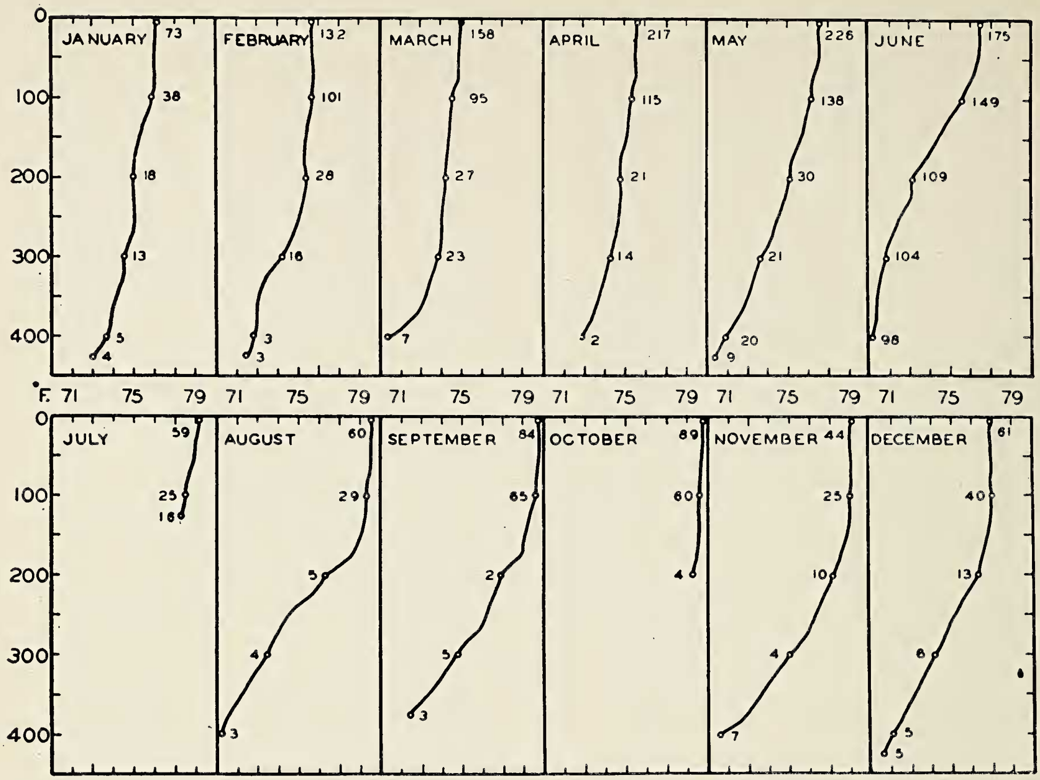


FIG. 22. Temperature depth curves; monthly averages (1941–1947); 20°–25° N, 155°–160° W.

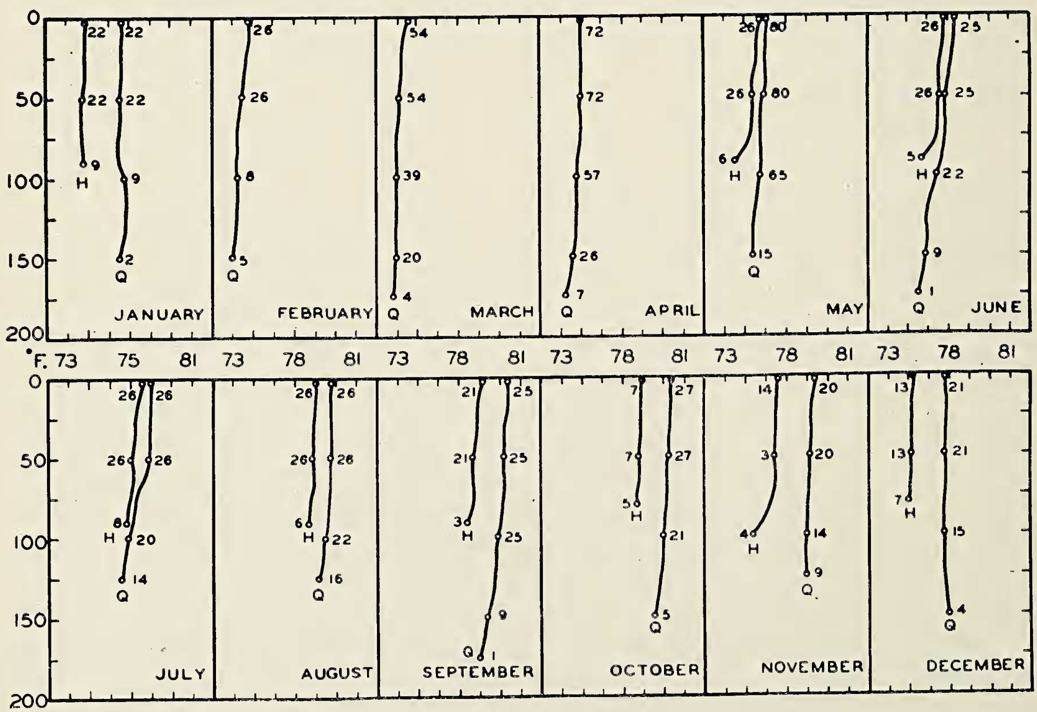


FIG. 23. Temperature depth curves; monthly averages. *H* cruises: March, 1944–February, 1945; 21° 18′ N–157° 53′ W. *Q* cruises: February, 1944–February, 1945; 21° 18′ N–157° 53′ W.

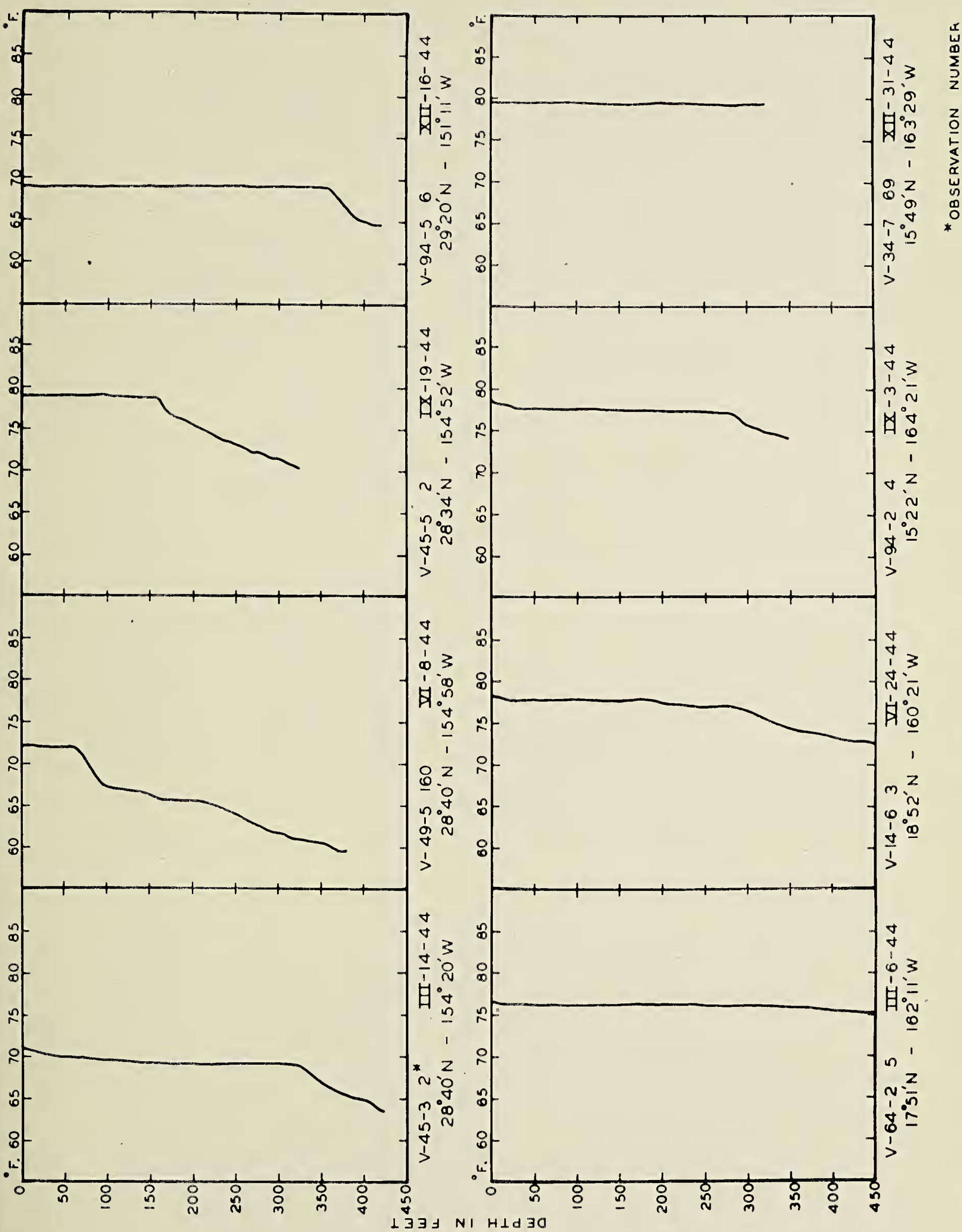


FIG. 24. Typical bathythermograms for March, June, September, December. Upper row, northern portion. Lower row, southern portion.

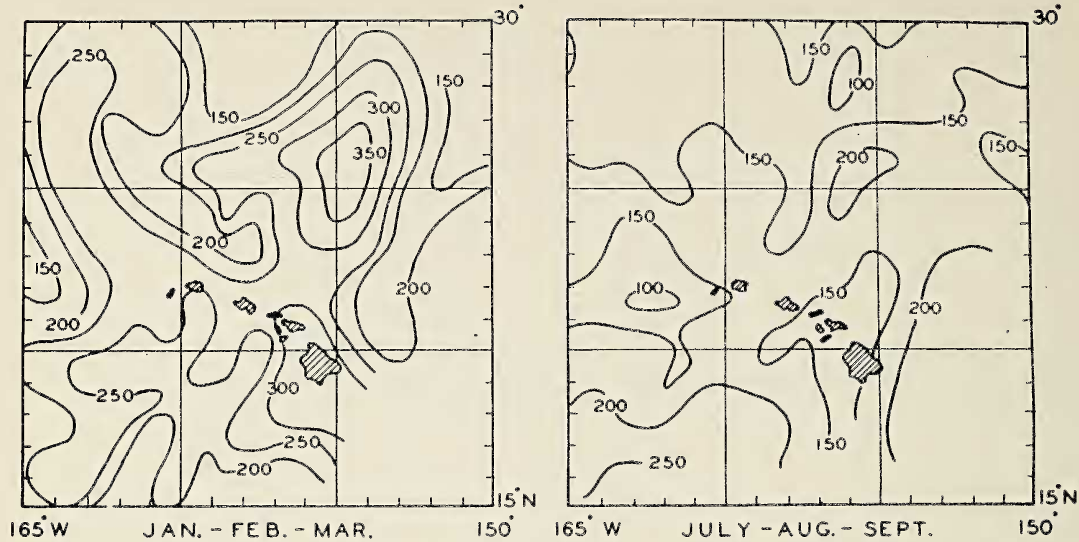


FIG. 25. Average depth of the virtually isothermal layer (1941–1947).

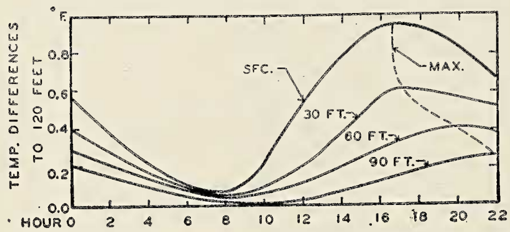
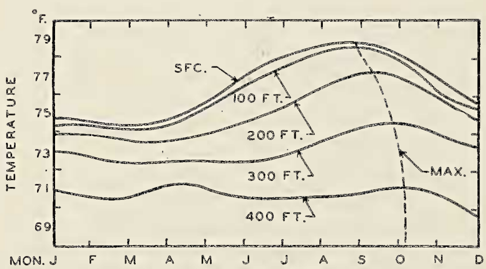


FIG. 26. Diurnal sea temperature variation (° F.); 21°–34° N, 138°–157° W.



NO. OF OBSERVATIONS

	J	F	M	A	M	J	J	A	S	O	N	D
SFC.	50	94	78	45	41	42	60	61	66	63	41	36
100′	50	69	75	44	42	41	58	61	63	61	36	35
200′	39	51	57	25	29	29	48	48	44	39	29	24
300′	33	45	47	21	28	26	39	38	36	27	19	20
400′	15	25	25	6	14	16	18	17	14	15	10	12

FIG. 27. Annual variation of temperature. 20°–25° N, 157°–160° W.